

TITLE: Atmospheric Propagation	
TDP NUMBER (NASA UPN): 314-30-119	WORK AREA MANAGER: George M. Resch
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RELATED TDP NUMBERS: 315-91-60	PHONE: 818-354-2789
RELATED DSDP NUMBERS: 132 (Cassini Ka-Band Radio Science)	FAX: 818-393-4965
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BRIEF TECHNICAL SUMMARY (*Objectives and Approach*)

This work area has two primary objectives. They are:

- 1) Develop and demonstrate a tropospheric calibration subsystem that will meet the 2-way Allan Standard Deviation requirement of 1.6×10^{-15} and attempt to meet the goal of 4×10^{-16} for 1000 to 10,000 sec. integration times as specified for the Cassini Gravitational Wave Experiment (GWE).
- 2) Develop the analysis methodology and establish a database that will enable the accurate calculation of tropospheric effects on telemetry, radio metrics, and radio science at all three DSN sites.

The task is organized into three work units, reflecting both the different objectives as well as the different line organizations that are cooperating in this endeavor. Each account has a Work Package Agreement (WPA) with the Task Manager. These account are:

JPL #412-41902-335, NASA #31430-119002, Title: Tropo. Cal. Perf. Demos

- Develop a detailed understanding of the atmospheric calibration error budget.
- Demonstrate the absolute performance of the calibration subsystem.
- Support WVR/GPS intercomparison experiments in order to evaluate the potential use of the GPS data type to estimate various meteorological parameters.

JPL #412-41904-386, NASA #31430-119004, Title: Adv. WVR Development

- Develop and build the prototype H/W for the Cassini GWE atmospheric calibration subsystem.
- Perform the simulations and analysis needed to quantify all aspects of the subsystem H/W design and performance.
- Support VLBI/WVR comparison experiments to verify all components of the calibration error budget.

JPL #412-41906-386, NASA #31430-119006, Title: WVR Statistics

- Develop a 32 GHz database of atmospheric brightness temperature at all three DSN sites to improve our understanding of atmospheric propagation effects.
- Evaluate the capability of WVR/GPS comparison data to calibrate the 22 GHz vapor line strength

APPROVALS		
WORK AREA MANAGER	DIVISION MANAGER	TMOD PROGRAM MANAGER
G. M. Resch	J. W. Layland	C. D. Edwards

JUSTIFICATION AND BENEFITS

The benefit of using the 32 GHz band (i.e. Ka-Band) for deep space communications is that it offers a factor of 3 to 6 times improvement in data rate over the current 8.4 GHz band. This improvement can be used for higher data rates or savings in spacecraft power and mass. The greatly reduced sensitivity to charged particle effects at 32 GHz also has benefits for some radio science experiments that are an integral part of deep space missions. A major disadvantage in using the 32 GHz band is the heightened sensitivity to atmospheric propagation effects as compared to lower frequency communication bands. It is imperative to understand these atmospheric effects on link performance if we want to quantify the cost to benefit ratio of establishing high frequency links as a capability for future missions. Calibration of some of these atmospheric effects is required to achieve radio science objectives.

The justification of this work area has two components. First, we are attempting to build a subsystem to calibrate minute fluctuations in the path delay due to the atmosphere to a level that has never been done. This subsystem will support the Cassini GWE, which if it successfully detects gravitational radiation will open an entirely new field of observational astronomy. Second, we are building a database of atmospheric effects for each DSN site that will precisely quantify the advantages and disadvantages of deep space communications at Ka-Band, and provide the means to plan communications strategy for future deep space missions.

APPROACH AND PLAN

The specific tasks fall into 2 categories, each with a different plan and approach.

1) TROPOSPHERIC CALIBRATION - The GWE has been approved by the Cassini mission and will be performed at 4 oppositions during the S/C cruise to Saturn. Analysis in preparation for this experiment has established the fact that fluctuations of tropospheric water vapor along the line of sight to the S/C will be a dominant source of error.

Several design studies during past years suggest that it is possible to build a subsystem that would sense small changes in apparent brightness temperature due to atmospheric water vapor, infer from these data the atmospheric phase fluctuations along the line of sight to the Cassini S/C, and thereby provide a calibration for the GWE. During the past year, laboratory testing and construction of an advanced radiometer (WVR) with enough instrumental stability to meet or exceed the GWE requirements has progressed well. Furthermore, analysis has shown that the retrieval errors can also be kept acceptably small with a reasonable set of supplementary instrumentation. In the coming year, we will attack the following areas:

- i) Verification of components in the atmospheric calibration error budget.
- ii) Calibration of the 22 GHz line strength.
- iii) Demonstration of the overall accuracy of our calibration.

In FY96 and FY97 we constructed a prototype of an advanced water vapor radiometer (AWVR) and were able to demonstrate we could measure and control the physical temperature of the various components to the required level of precision. In FY98, we will be constructing a second unit and will subject these instruments to the kind of conditions likely to be experienced in a field deployment. We will compare the AWVRs with each other in order to test our calculations of beam smearing and beam mismatch as well as instrumental stability.

In FY 97, we began to measure and assess the effects of horizontal temperature gradients on the dry delay mapping function, using *in-situ* aircraft measurements at Goldstone conducted by MJ Mahoney. Evaluation of the limited data set suggested that the horizontal temperature gradients not be as significant an error source as previously believed. However, a more extensive set of Goldstone aircraft data, under expected GWE troposphere conditions, is required to assess the severity and calibration requirements of the horizontal gradient effect. These measurements are planned for early CY98 during winter night conditions.

In FY95 we had a impressive demonstration of the capability of the existing WVRs to calibrate atmospheric fluctuations. Lacking a spacecraft, we used two WVRs in a VLBI experiment between

DSS 13 and DSS 15 and were able to show that the VLBI group delay residuals, which are dominated by atmospheric water vapor fluctuations, were decreased by nearly a factor of three when we applied the WVR calibration data. Equally important, the small remaining differences after calibration are explained by instrumental noise and the fact that the WVRs were offset from the VLBI antennas and had larger beams. In effect, the demonstration gave us confidence that we have a semi-quantitative understanding of the entire error budget for WVR calibration of the GWE.

We intend to repeat these demonstrations in FY98 with AWRs, because it is absolutely essential for the GWE that each subsystem in the experiment independently establish its contribution to the overall error budget. In the event a GW is not detected, the primary importance of the experiment will be to establish a detection limit. In order to do this with high confidence, each part of the GWE observing system must demonstrate its absolute error, which in turn must be consistent with the observed noise level in the data. We will demonstrate a 32 GHz VLBI capability between stations at the Goldstone complex and evaluate the VLBI system stability in CY98.

In FY98 we will perform an inexpensive measurements (but believed to be sufficiently accurate) to calibrate the 22 GHz line strength. This new approach utilizes phase tracking of the GPS satellites in very humid conditions and simultaneous observations with WVRs. Initial GPS/WVR comparisons in California in FY96 and FY97 demonstrated that this technique is feasible. In FY98, the GPS receiver and a WVR will be deployed to a very humid site.

2) TROPOSPHERIC STATISTICS - Calculation of the performance for a deep space communications link usually must be done days, weeks, or years ahead of the time the link is actually used. Atmospheric effects, which are highly variable, both attenuate the link and add noise to the system. Typically, these atmospheric effects are included in link calculation in a statistical sense, utilizing a cumulative probability distribution (CPD) that quantifies the fraction of time that some measure of the atmosphere exceeds a specified level. Our understanding of the benefits of Ka-Band as compared to X-Band is directly proportional to our confidence in the CPD for the atmosphere.

Preliminary estimates for the CPD exist for all three DSN sites and clearly demonstrate that, a) Ka-Band offers significant performance improvements over X-Band links, and b) there is a large variation between DSN sites. It is now vitally important to increase our confidence in the CPD models and investigate how they may vary by day or season.

The significance of a CPD model rests on the amount of data used to calculate the CPD and the assertion that the database spans all possible atmospheric variations. For deep space links that typically work with 1 - 2 dB margins, we desire a model accuracy of 0.1 dB in the link calculations which corresponds to roughly 1K accuracy in the CPD model in the 90 to 95% confidence regime. This implies a data set spanning over a decade.

WVRs have been deployed at Madrid (since 1990) and Goldstone (since 1993) to gather CPD data by direct measurement. In FY98 an existing WVR will be refurbished and installed in Australia.

FUTURE PLANS - For the next year or two the primary focus of this work area will be to lower the remaining uncertainty and risk in our ability to implement a calibration subsystem for the Cassini GWE. We will concentrate on building two prototypes, demonstrating improved performance, and understanding the detailed design of the system that will be deployed to support Cassini Radio Science.

As Implementation funding began in FY97, our resources shifted from building hardware and doing simulations to performance demonstration. Once we have established a high degree of confidence in our calibration accuracy, there will be another shift of resources toward the Statistics area.

On August 18, 1999, the Cassini spacecraft will flyby the Earth and head for a rendezvous with Saturn. Shortly thereafter, the spacecraft will be in opposition from the Sun but the round trip light time is too short to be scientifically interesting to the GWE experimenters. The actual GWE is scheduled to start Nov. 29, 2000. However, the 1999 date is a perfect opportunity to test the overall error budget of the various ground support systems, the spacecraft error contributions, and serve as an operational readiness test. It is quite possible that we could assemble all of the elements (prototype equipment) of the atmospheric calibration subsystem in order to support a test in late-99. It is not so clear that the other elements needed for the test will be in-place. There is an immediate need for central coordination of this test within the DSN Technology Program.



DSN TECHNOLOGY DEVELOPMENT PLAN

TDP NUMBER: 314-30-119

Atmospheric Propagation

DELIVERABLES

ITEM	FROM/TO	DATE
1) Horizontal gradient measurements at Goldstone	M. Mahoney/G. Resch	1 May 98
2) GPS/WVR Comparison Prog Rept -2 Emission model improvement	Task/G. Resch	1 Dec 98
3) WVR/WVR Comparison Prog Rept -1	A. Tanner/G. Resch	1 Sep 98

RESOURCE REQUIREMENTS

<u>Work Unit</u>	<u>JPL Account #</u>	<u>NASA UPN</u>	<u>FY98</u>	<u>FY99</u>	<u>FY00</u>	<u>FY01</u>	<u>FY02</u>	<u>FY03</u>
			(\$K)	(\$K)	(\$K)	(\$K)	(\$K)	(\$K)
Tropo Cal Perf Demos	412-41902-335	31430-119002	200	0	0	0	0	0
Adv WVR Development	412-41904-386	31430-119004	184	0	0	0	0	0
WVR Stats	412-41906-386	31430-119006	70	0	0	0	0	0
Atmos Prop Adv Dev	412-41990-386	31430-119090	0	716	677	647	672	672
TOTAL FUNDING			454	716	677	647	672	672



DSN TECHNOLOGY DEVELOPMENT PLAN

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SCHEDULE

Atmospheric Propagation	FY98				FY99		FY00	FY01	FY02	FY03
	Q1	Q2	Q3	Q4	Q1/2	Q3/4				
Tropo. Calib. Performance Demos										
GPS/WVR comparison - Phase 1	■									
Dry mapping function study		■	■	■						
GPS/WVR comparison - Phase 2		■	■	■	■					
WVR/VLBI comparison				■	■	■				
WVR Development										
WVR/WVR comparison			■	■	■					
WVR Statistics										
WVR maintenance & operation										
WVR installation at SPC-40	■	■								
Re-install WVR at SPC-60	■	■	■							
Resources by FY (\$K):	454				716		677	647	672	672